US008780880B2

(12) **United States Patent**
Lin et al.

(10) **Patent No.: US 8,780,880 B2**
(45) **Date of Patent: Jul. 15, 2014**

(54) **METHOD OF TDM IN-DEVICE COEXISTENCE INTERFERENCE AVOIDANCE**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 283 days.

(21) Appl. No.: **13/200,775**

(22) Filed: **Sep. 29, 2011**

(65) **Prior Publication Data**

US 2012/0082140 A1 Apr. 5, 2012

Related U.S. Application Data

(60) Provisional application No. 61/388,687, filed on Oct. 1, 2010.

(51) **Int. Cl.**
H04J 3/00 (2006.01)

(52) **U.S. Cl.**
USPC **370/345**; 370/458; 370/498

(58) **Field of Classification Search**
CPC H04W 88/06; H04W 72/1215; H04W 72/1289; H04L 5/0053; H04L 1/00
See application file for complete search history.

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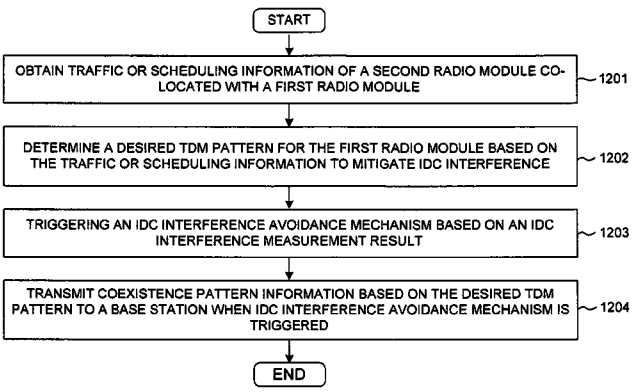
(57) **ABSTRACT**

A method of TDM in-device coexistence (IDC) interference avoidance is proposed. In a wireless communication device, a first radio module is co-located with a second radio module in the same device platform. The first radio module obtains traffic and scheduling information of the second radio module. The first radio module then determines a desired TDM pattern based on the traffic and scheduling information to prevent IDC interference with the second radio module. The first radio module also transmits TDM coexistence pattern information based on the desired TDM pattern to a base station. In one embodiment, the TDM coexistence pattern information comprises a recommended TDM pattern periodicity and a scheduling period to maximize IDC efficiency subject to limited level of IDC interference possibility. In one specific example, the TDM coexistence pattern information comprises a set of discontinuous reception (DRX) configuration parameters defined in long-term evolution (LTE) 3GPP standards.

20 Claims, 8 Drawing Sheets



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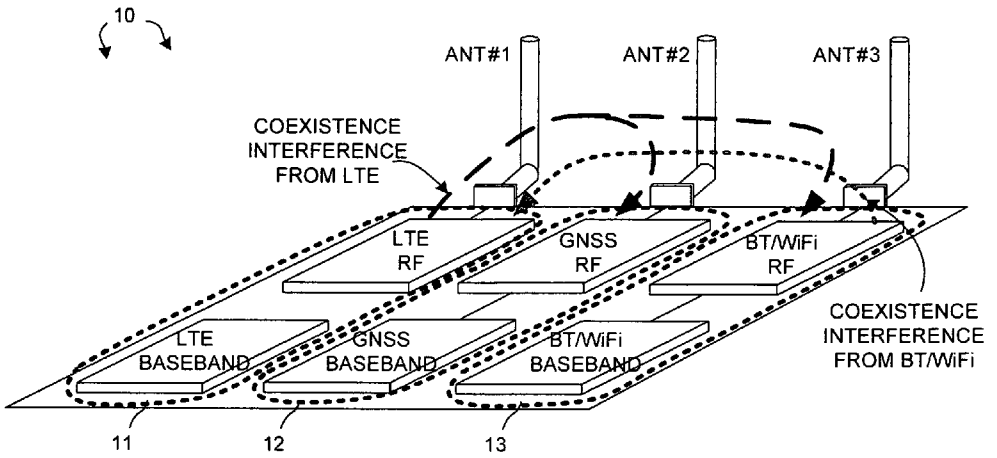
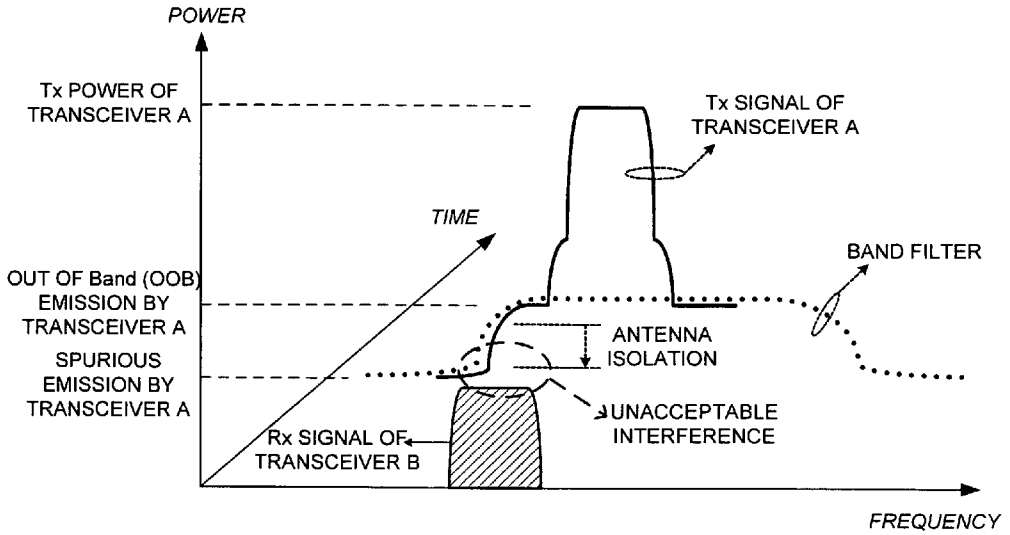


(Prior Art)
FIG. 1



(Prior Art)
FIG. 2

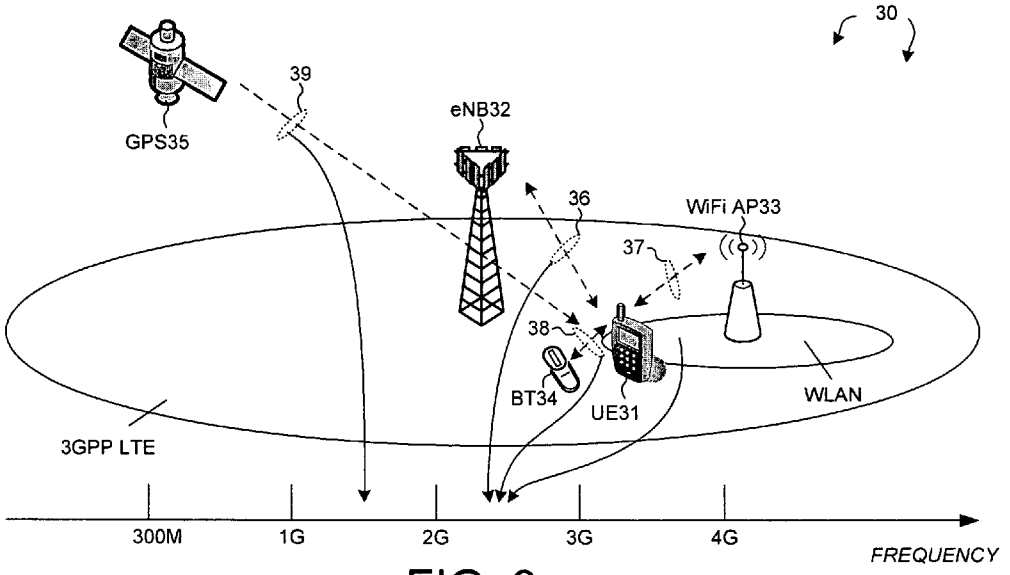

30
39
GPS35
eNB32
36
WiFi AP33
37
38
BT34
UE31
WLAN
3GPP LTE
300M
1G
2G
3G
4G
FREQUENCY

FIG. 3

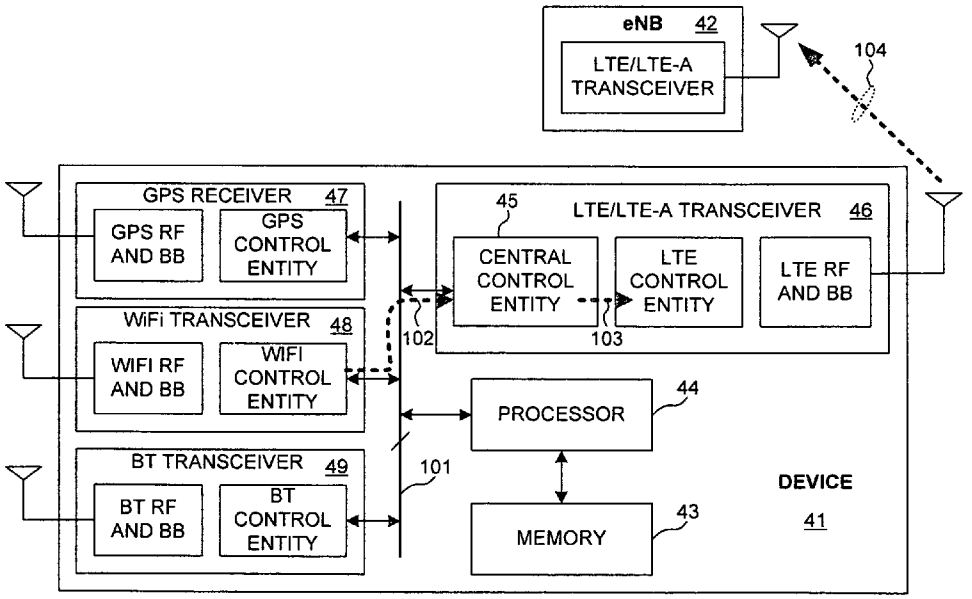

eNB 42
LTE/LTE-A TRANSCEIVER
104
GPS RECEIVER 47
GPS RF AND BB
GPS CONTROL ENTITY
WiFi TRANSCEIVER 48
WIFI RF AND BB
WIFI CONTROL ENTITY
BT TRANSCEIVER 49
BT RF AND BB
BT CONTROL ENTITY
45
LTE/LTE-A TRANSCEIVER 46
CENTRAL CONTROL ENTITY
LTE CONTROL ENTITY
LTE RF AND BB
102
103
PROCESSOR
44
MEMORY
43
101
DEVICE
41

FIG. 4

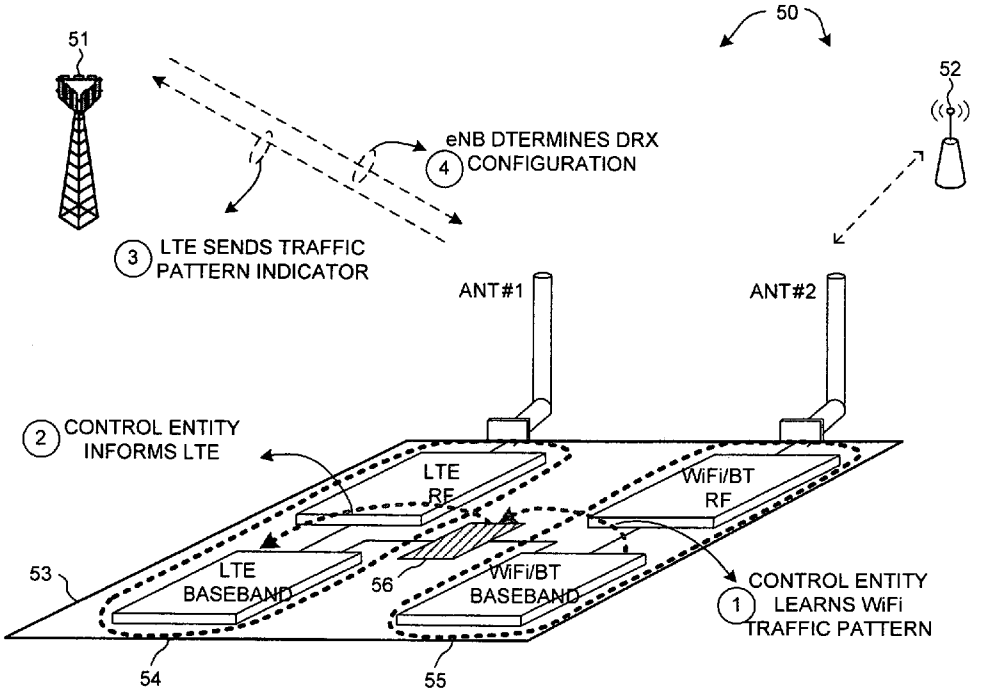

50
51
52
eNB DTERMINES DRX
4 CONFIGURATION
3 LTE SENDS TRAFFIC
PATTERN INDICATOR
ANT#1
ANT#2
2 CONTROL ENTITY
INFORMS LTE
LTE
RF
WiFi/BT
RF
53
LTE
BASEBAND
56
WiFi/BT
BASEBAND
1 CONTROL ENTITY
LEARNS WiFi
TRAFFIC PATTERN
54
55

FIG. 5

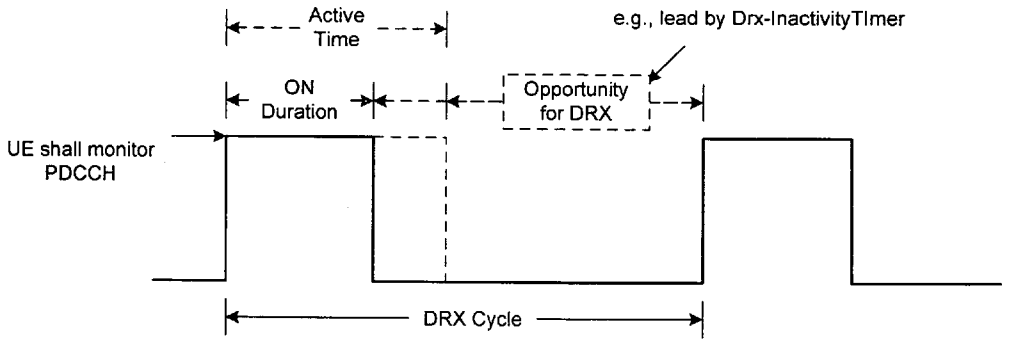

Active
Time
e.g., lead by Drx-InactivityTImer
ON
Duration
Opportunity
for DRX
UE shall monitor
PDCCH
DRX Cycle

FIG. 6

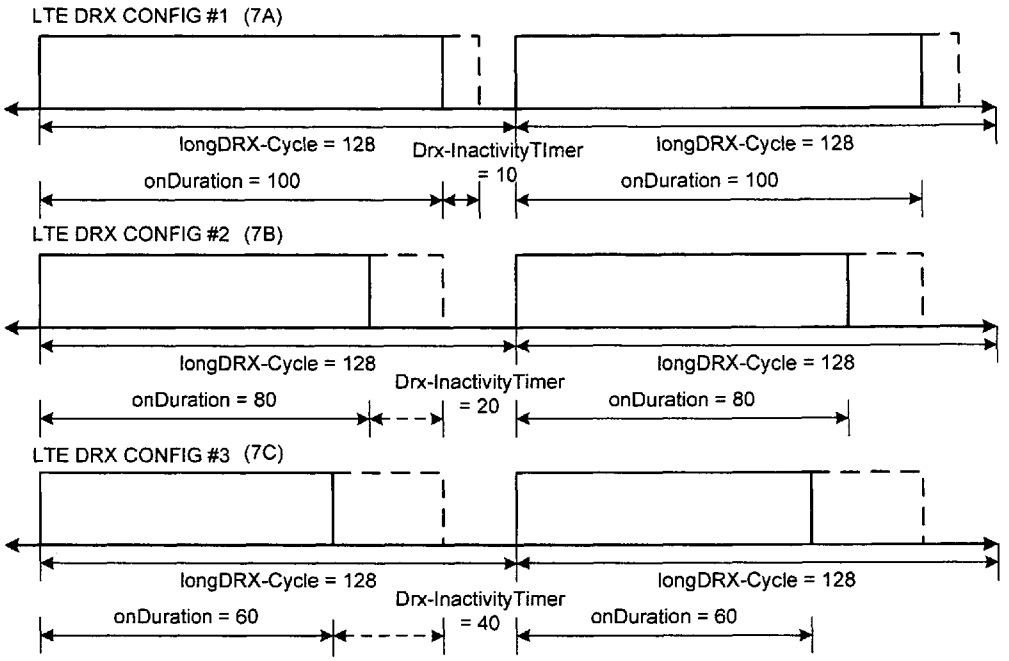

LTE DRX CONFIG #1 (7A)
longDRX-Cycle = 128
Drx-InactivityTImer = 10
longDRX-Cycle = 128
onDuration = 100
onDuration = 100
LTE DRX CONFIG #2 (7B)
longDRX-Cycle = 128
longDRX-Cycle = 128
Drx-InactivityTimer = 20
onDuration = 80
onDuration = 80
LTE DRX CONFIG #3 (7C)
longDRX-Cycle = 128
longDRX-Cycle = 128
Drx-InactivityTimer = 40
onDuration = 60
onDuration = 60

FIG. 7

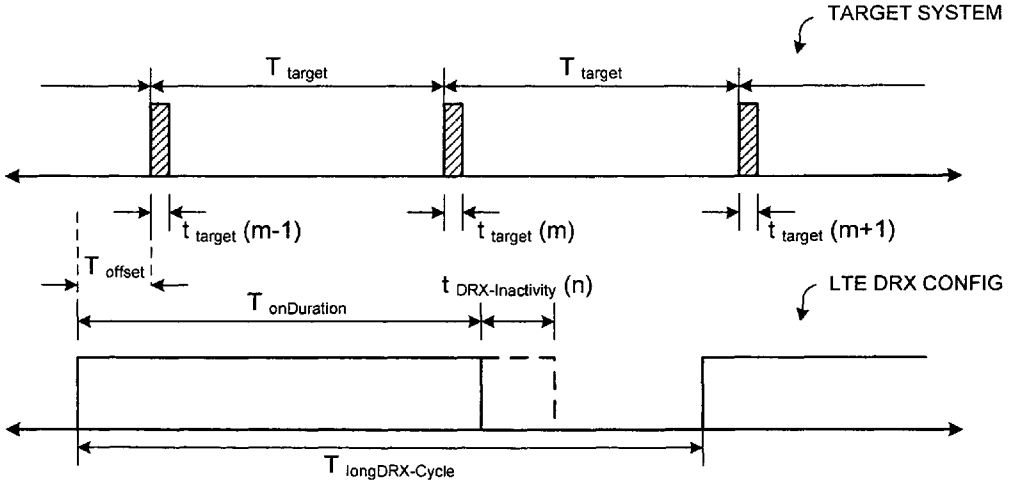

TARGET SYSTEM
T target
T target
t target (m-1)
t target (m)
t target (m+1)
T offset
T onDuration
t DRX-Inactivity (n)
LTE DRX CONFIG
T longDRX-Cycle

FIG. 8

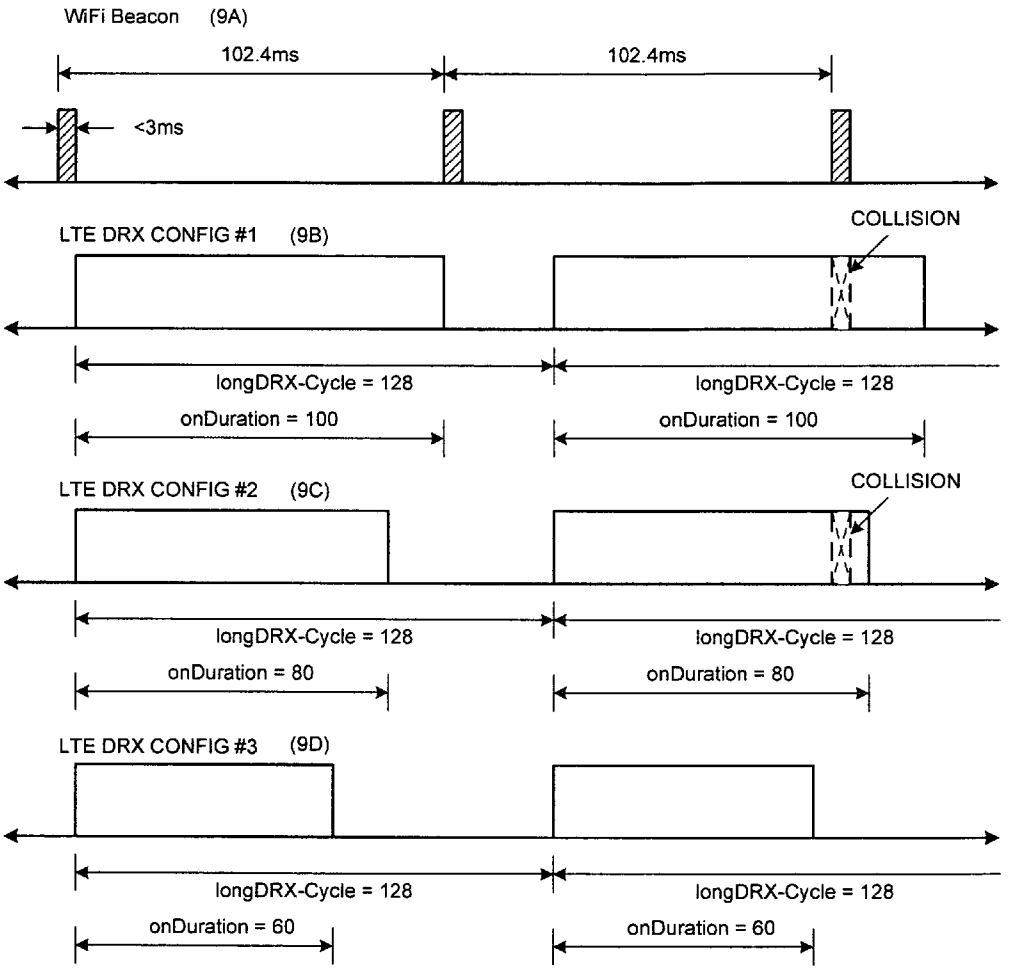

WiFi Beacon (9A)
102.4ms
102.4ms
<3ms
LTE DRX CONFIG #1 (9B)
COLLISION
longDRX-Cycle = 128
longDRX-Cycle = 128
onDuration = 100
onDuration = 100
LTE DRX CONFIG #2 (9C)
COLLISION
longDRX-Cycle = 128
longDRX-Cycle = 128
onDuration = 80
onDuration = 80
LTE DRX CONFIG #3 (9D)
longDRX-Cycle = 128
longDRX-Cycle = 128
onDuration = 60
onDuration = 60

FIG. 9

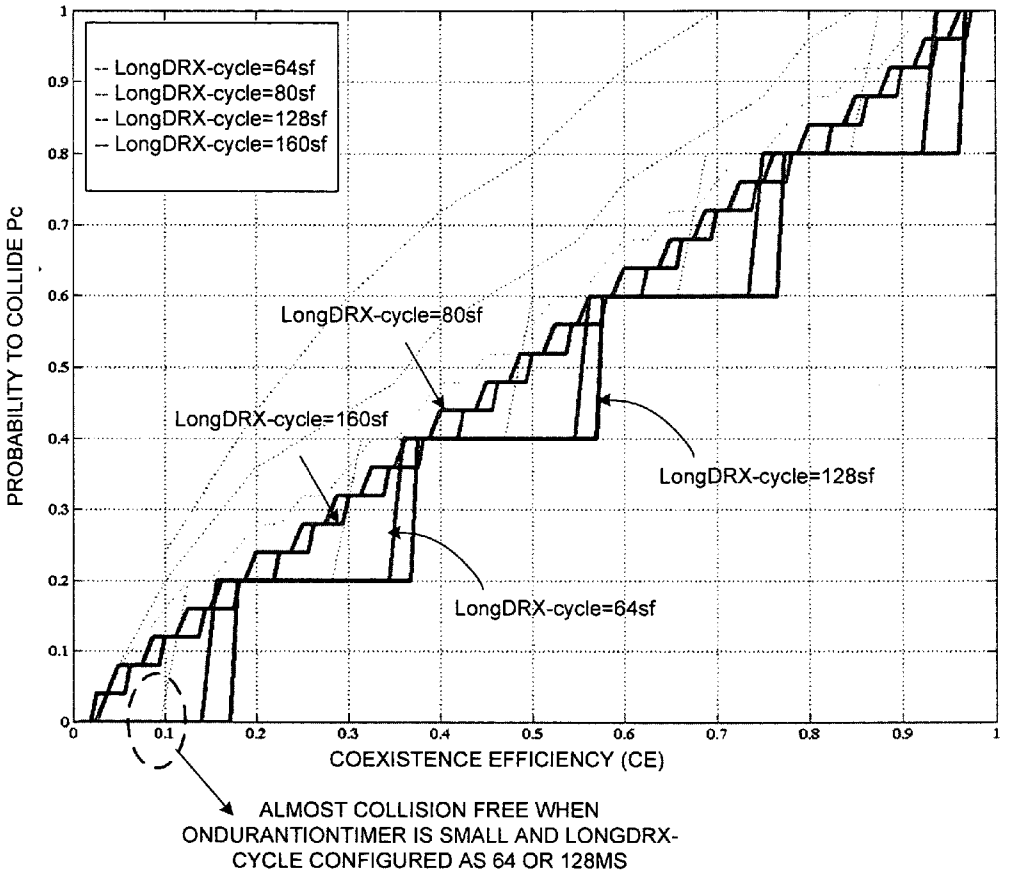

-- LongDRX-cycle=64sf
-- LongDRX-cycle=80sf
-- LongDRX-cycle=128sf
-- LongDRX-cycle=160sf
PROBABILITY TO COLLIDE Pc
COEXISTENCE EFFICIENCY (CE)
LongDRX-cycle=80sf
LongDRX-cycle=160sf
LongDRX-cycle=128sf
LongDRX-cycle=64sf
ALMOST COLLISION FREE WHEN ONDURANTIONTIMER IS SMALL AND LONGDRX-CYCLE CONFIGURED AS 64 OR 128MS

FIG. 10

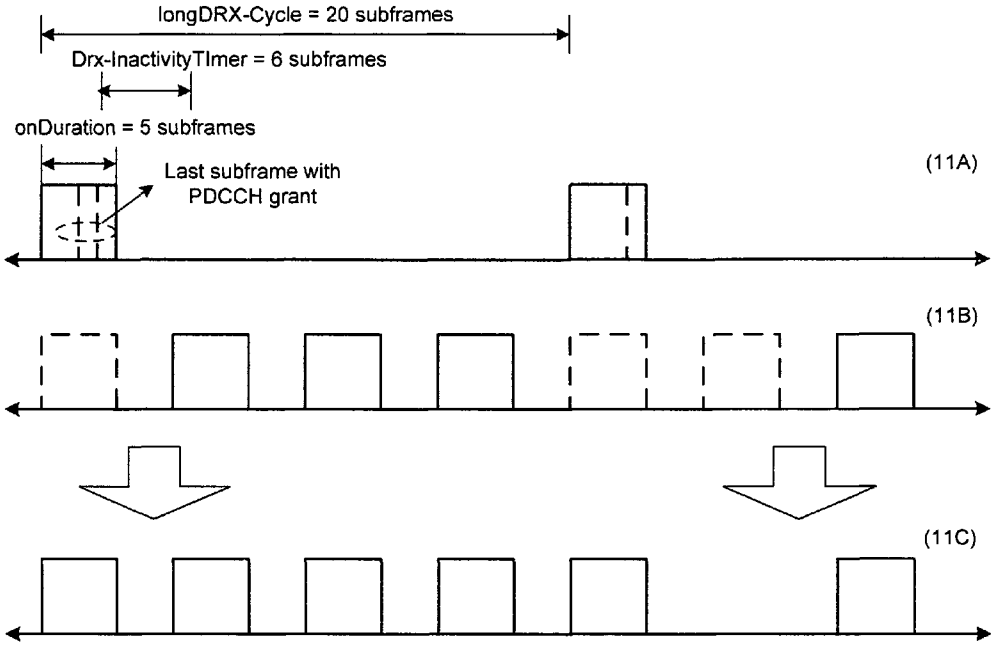

longDRX-Cycle = 20 subframes
Drx-InactivityTImer = 6 subframes
onDuration = 5 subframes
Last subframe with PDCCH grant
(11A)
(11B)
(11C)

FIG. 11

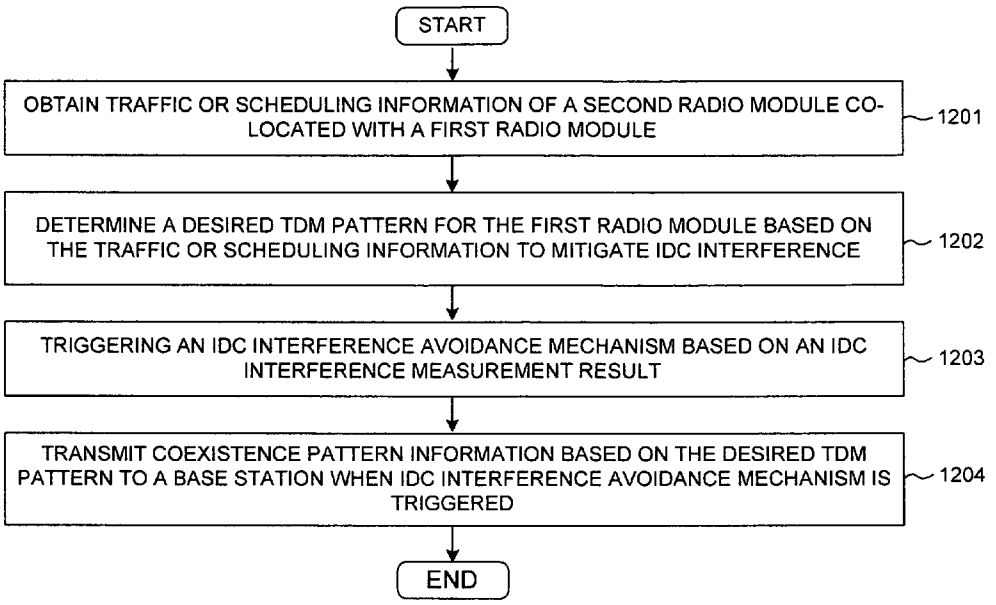

START
OBTAIN TRAFFIC OR SCHEDULING INFORMATION OF A SECOND RADIO MODULE CO-LOCATED WITH A FIRST RADIO MODULE
1201
DETERMINE A DESIRED TDM PATTERN FOR THE FIRST RADIO MODULE BASED ON THE TRAFFIC OR SCHEDULING INFORMATION TO MITIGATE IDC INTERFERENCE
1202
TRIGGERING AN IDC INTERFERENCE AVOIDANCE MECHANISM BASED ON AN IDC INTERFERENCE MEASUREMENT RESULT
1203
TRANSMIT COEXISTENCE PATTERN INFORMATION BASED ON THE DESIRED TDM PATTERN TO A BASE STATION WHEN IDC INTERFERENCE AVOIDANCE MECHANISM IS TRIGGERED
1204
END

FIG. 12

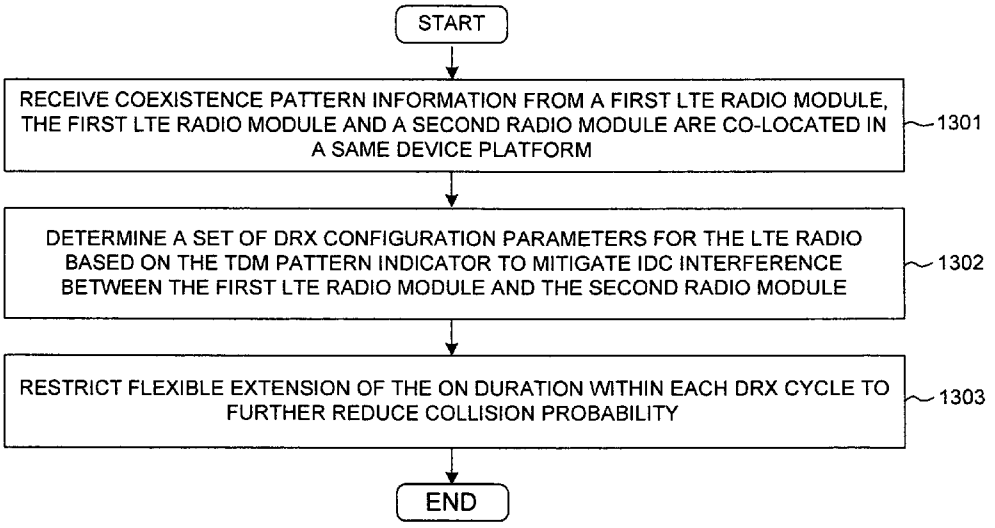

START
RECEIVE COEXISTENCE PATTERN INFORMATION FROM A FIRST LTE RADIO MODULE, THE FIRST LTE RADIO MODULE AND A SECOND RADIO MODULE ARE CO-LOCATED IN A SAME DEVICE PLATFORM
1301
DETERMINE A SET OF DRX CONFIGURATION PARAMETERS FOR THE LTE RADIO BASED ON THE TDM PATTERN INDICATOR TO MITIGATE IDC INTERFERENCE BETWEEN THE FIRST LTE RADIO MODULE AND THE SECOND RADIO MODULE
1302
RESTRICT FLEXIBLE EXTENSION OF THE ON DURATION WITHIN EACH DRX CYCLE TO FURTHER REDUCE COLLISION PROBABILITY
1303
END

FIG. 13

METHOD OF TDM IN-DEVICE COEXISTENCE INTERFERENCE AVOIDANCE

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims priority under 35 U.S.C. §119 from U.S. Provisional Application No. 61/388,687, entitled "Method of TDM In-Device Coexistence Interference Avoidance," filed on Oct. 1, 2010, the subject matter of which is incorporated herein by reference.

TECHNICAL FIELD

The disclosed embodiments relate generally to wireless network communications, and, more particularly, to TDM solutions for in-device coexistence (IDC) interference avoidance.

BACKGROUND

Ubiquitous network access has been almost realized today. From network infrastructure point of view, different networks belong to different layers (e.g., distribution layer, cellular layer, hot spot layer, personal network layer, and fixed/wired layer) that provide different levels of coverage and connectivity to users. Because the coverage of a specific network may not be available everywhere, and because different networks may be optimized for different services, it is thus desirable that user devices support multiple radio access networks on the same device platform. As the demand for wireless communication continues to increase, wireless communication devices such as cellular telephones, personal digital assistants (PDAs), smart handheld devices, laptop computers, tablet computers, etc., are increasingly being equipped with multiple radio transceivers. A multiple radio terminal (MRT) may simultaneously include a Long-Term Evolution (LTE) or LTE-Advanced (LTE-A) radio, a Wireless Local Area Network (WLAN, e.g., WiFi) access radio, a Bluetooth (BT) radio, and a Global Navigation Satellite System (GNSS) radio.

Due to spectrum regulation, different technologies may operate in overlapping or adjacent radio spectrums. For example, LTE/LTE-A TDD mode often operates at 2.3-2.4 GHz, WiFi often operates at 2.400-2.483.5 GHz, and BT often operates at 2.402-2.480 GHz. Simultaneous operation of multiple radios co-located on the same physical device, therefore, can suffer significant degradation including significant coexistence interference between them because of the overlapping or adjacent radio spectrums. Due to physical proximity and radio power leakage, when the transmission of signal for a first radio transceiver overlaps with the reception of signal for a second radio transceiver in time domain, the second radio transceiver reception can suffer due to interference from the first radio transceiver transmission. Likewise, signal transmission of the second radio transceiver can interfere with signal reception of the first radio transceiver.

FIG. **1** (Prior Art) is a diagram that illustrates interference between an LTE transceiver and a co-located WiFi/BT transceiver and GNSS receiver. In the example of FIG. **1**, user equipment (UE) **10** is an MRT comprising an LTE transceiver **11**, a GNSS receiver **12**, and a BT/WiFi transceiver **13** co-located on the same device platform. LTE transceiver **11** comprises an LTE baseband module and an LTE RF module coupled to an antenna #**1**. GNSS receiver **12** comprises a GNSS baseband module and a GNSS RF module coupled to antenna #**2**. BT/WiFi transceiver **13** comprises a BT/WiFi baseband module and a BT/WiFi RF module coupled to antenna #**3**. When LTE transceiver **11** transmits radio signals, both GNSS receiver **12** and BT/WiFi transceiver **13** may suffer coexistence interference from LTE. Similarly, when BT/WiFi transceiver **13** transmits radio signals, both GNSS receiver **12** and LTE transceiver **11** may suffer coexistence interference from BT/WiFi. How UE**10** can simultaneously communicate with multiple networks through different transceivers and avoid/reduce coexistence interference is a challenging problem.

FIG. **2** (Prior Art) is a diagram that illustrates the signal power of radio signals from two co-located RF transceivers. In the example of FIG. **2**, transceiver A and transceiver B are co-located in the same device platform (i.e., in-device). The transmit (TX) signal by transceiver A (e.g., WiFi TX in ISM CH1) is very close to the receive (RX) signal (e.g., LTE RX in Band **40**) for transceiver B in frequency domain. The out of band (OOB) emission and spurious emission resulted by imperfect TX filter and RF design of transceiver A may be unacceptable to transceiver B. For example, the TX signal power level by transceiver A may be still higher (e.g. 60 dB higher before filtering) than RX signal power level for transceiver B even after the filtering (e.g., after 50 dB suppression).

In addition to imperfect TX filter and RF design, imperfect RX filter and RF design may also cause unacceptable in-device coexistence interference. For example, some RF components may be saturated due to transmit power from another in-device transceiver but cannot be completely filtered out, which results in low noise amplifier (LNA) saturation and cause analog to digital converter (ADC) to work incorrectly. Such problem actually exists regardless of how much the frequency separation between the TX channel and the RX channel is. This is because certain level of TX power (e.g., from a harmonic TX signal) may be coupled into the RX RF frontend and saturate its LNA. If the receiver design does not consider such coexistence interference, the LNA may not be adapted at all and keep saturated until the coexistence interference be removed (e.g. by turning off the interference source).

Various in-device coexistence (IDC) interference avoidance solutions have been proposed. For example, an UE may request network assistance to prevent IDC interference via frequency division multiplexing (FDM), time division multiplexing (TDM), and/or power management principles. The major concerns on TDM solutions are how much complexity to eNB scheduler, how UE can help eNB generate proper gaps, how UE can utilize the gaps generated by eNB, how much performance improvement can be achieved, and how much impact to the existing LTE/LTE-A standard specifications. Possible TDM solutions include DRX/DTX, measurement, SPS, MBMS, scheduling via PDCCH, and a new protocol. It is desirable to find a TDM solution that can generate the TX/RX gaps with more flexibility and less impact to existing design and implementation.

SUMMARY

A method of TDM in-device coexistence (IDC) interference avoidance is proposed. In a wireless communication device, a first radio module is co-located with a second radio module in the same device platform. The first radio module obtains traffic and scheduling information of the second radio module. The first radio module then determines a desired TDM pattern based on the traffic and scheduling information to prevent IDC interference with the second radio module. The first radio module also transmits TDM coexistence pat-

tern information based on the desired TDM pattern to a base station (eNB). In one embodiment, the TDM coexistence pattern information comprises a recommended TDM pattern periodicity and a scheduling period to maximize IDC efficiency subject to limited level of IDC interference possibility.

In one specific example, the TDM coexistence pattern information comprises a set of discontinuous reception (DRX) configuration parameters defined in 3GPP long-term evolution (LTE) standards. If the second radio module is a WiFi radio having WiFi beacon signal periodicity of 102.4 ms, then the eNB configures DRX operation with a longDRX-Cycle equal to 128 ms or 64 ms, and the OnDurationTimer is small enough such that collision probability between the first and the second radio modules is lower than a threshold value. Upon receiving an IDC interference indication, the eNB may restrict some flexible extension of an ON duration within each DRX cycle to further reduce collision probability.

Other embodiments and advantages are described in the detailed description below. This summary does not purport to define the invention. The invention is defined by the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, where like numerals indicate like components, illustrate embodiments of the invention.

FIG. **1** (Prior Art) is a diagram that illustrates interference between an LTE transceiver and a co-located WiFi/BT transceiver and GNSS receiver.

FIG. **2** (Prior Art) is a diagram that illustrates the signal power of radio signals from two co-located RF transceivers in a same device platform.

FIG. **3** illustrates a user equipment having multiple radio transceivers in a wireless communication system in accordance with one novel aspect.

FIG. **4** is a simplified block diagram of a wireless device having a central control entity.

FIG. **5** illustrates one embodiment of TDM solution for IDC interference avoidance in accordance with one novel aspect.

FIG. **6** illustrates a basic DRX cycle and corresponding DRX configuration parameters.

FIG. **7** illustrates examples of LTE DRX traffic patterns with different DRX configuration parameters.

FIG. **8** illustrates traffic pattern and scheduling parameters of an LTE system and an ISM target system for coexistence problems.

FIG. **9** illustrates examples of various LTE DRX configurations that coexist with WiFi Beacon.

FIG. **10** is a simulation diagram of Probability to Collide vs. Coexistence Efficiency under different DRX configuration parameters.

FIG. **11** illustrates possible modifications on existing DRX protocol.

FIG. **12** is a flow chart of a method of TDM solution for IDC interference avoidance from UE perspective in accordance with one novel aspect.

FIG. **13** is a flow chart of a method of TDM solution for IDC interference avoidance from eNB perspective in accordance with one novel aspect.

DETAILED DESCRIPTION

Reference will now be made in detail to some embodiments of the invention, examples of which are illustrated in the accompanying drawings.

FIG. **3** illustrates a user equipment UE**31** having multiple radio transceivers in a wireless communication system **30** in accordance with one novel aspect. Wireless communication system **30** comprises a user equipment UE**31**, a serving base station (e.g., evolved node-B) eNB**32**, a WiFi access point WiFi AP**33**, a Bluetooth device BT**34**, and a global positioning system satellite device GPS**35**. Wireless communication system **30** provides various network access services for UE**31** via different radio access technologies. For example, eNB**32** provides OFDMA-based cellular radio network (e.g., a 3GPP Long-Term Evolution (LTE) or LTE-Advanced (LTE-A) system) access, WiFi AP**33** provides local coverage in Wireless Local Area Network (WLAN) access, BT**34** provides short-range personal network communication, and GPS**35** provides global access as part of a Global Navigation Satellite System (GNSS). To access various radio networks, UE**31** is a multi-radio terminal (MRT) that is equipped with multiple radios coexisted/co-located in the same device platform (i.e., in-device).

Due to spectrum regulation, different radio access technologies may operate in overlapping or adjacent radio spectrums. As illustrated in FIG. **3**, UE**31** communicates radio signal **36** with eNB**32**, radio signal **37** with WiFi AP**33**, radio signal **38** with BT**34**, and receives radio signal **39** from GPS**35**. Radio signal **36** belongs to 3GPP Band **40**, radio signal **37** belongs to one of the WiFi channels, and radio signal **38** belongs to one of the seventy-nine Bluetooth channels. The frequencies of all those radio signals fall within a range from 2.3 GHz to 2.5 GHz, which may result in significant in-device coexistence (IDC) interference to each other. The problem is more severe around the 2.4 GHz ISM (The Industrial, Scientific and Medical) radio frequency band. Various IDC interference avoidance solutions have been proposed. In one novel aspect, UE**31** triggers specific Time Division Multiplexing (TDM)-based solutions for IDC interference avoidance. The TDM-based solutions require internal device coordination, such as a central control entity that communicates with the multiple radios within UE**31**.

FIG. **4** is a simplified block diagram of a wireless device **41** having a central control entity to facilitate TDM solutions for IDC interference avoidance. Wireless device **41** comprises memory **43**, a processor **44**, a central control entity **45**, an LTE transceiver **46**, a GPS receiver **47**, a WiFi transceiver **48**, a Bluetooth transceiver **49**, and bus **101**. In the example of FIG. **4**, central control entity **45** is a logical entity physically implemented within the LTE transceiver **46**. Alternatively, central control entity **45** can be a logical entity implemented within a processor that is physically located within WiFi transceiver **48**, BT transceiver **49**, or processor **44** that is also used for device application processing for device **41**. Central control entity **45** is connected to various transceivers within device **41**, and communicates with the various transceivers via bus **101**.

For example, WiFi transceiver **48** transmits WiFi signal information and/or WiFi traffic and scheduling information to central control entity **45** (e.g., depicted by a dotted line **102**). Based on the received WiFi information, central control entity **45** determines control information and transmits the control information to LTE transceiver **46** (e.g., depicted by a dotted line **103**). In one embodiment, LTE transceiver **46** learns the WiFi activity through control entity **45** and detects IDC interference between LTE and WiFi. LTE transceiver **46** triggers TDM solution for IDC interference avoidance and communicates with its serving base station eNB**42** to indicate a recommended TDM coexistence pattern (e.g., depicted by a dotted line **104**). Based on the TDM coexistence pattern infor-

mation, eNB**42** is able to determine the best suitable TDM solution for device **41** to prevent IDC interference between LTE and WiFi effectively.

FIG. **5** illustrates one embodiment of TDM solution for IDC interference avoidance in wireless network **50** in accordance with one novel aspect. Wireless network **50** comprises an eNB**51**, a WiFi AP**52**, and an UE**53**. UE**53** comprises an LTE radio module (e.g., transceiver) **54**, an ISM BT/WiFi radio module (e.g., transceiver) **55**, and a central control entity **56**. In one novel aspect, control entity **56** learns ISM Tx/Rx activity from BT/WiFi transceiver **55** (step **1**) and informs the ISM Tx/Rx timing information to LTE transceiver **54** (step **2**). Based on the ISM Tx/Rx timing information, LTE radio module **54** triggers IDC interference avoidance mechanism and indicates a recommended coexistence pattern to eNB**51** (step **3**). In addition, LTE radio module **54** may also reports ISM traffic and scheduling information to eNB**51** to further assist IDC configuration. Based on the received coexistence pattern information, eNB**51** determines the best suitable TDM solution for UE**53** to prevent IDC interference (step **4**). In one specific embodiment, eNB**51** configures UE**53** with discontinuous reception (DRX) operation that controls the ON/OFF cycle and Tx/Rx activity of UE**53** by configuring a set of DRX parameters.

FIG. **6** illustrates a basic DRX cycle and corresponding DRX configuration parameters. A basic DRX cycle consists of an ON Duration (e.g., sometimes referred to as a scheduling period) and an Opportunity for DRX Duration. In RRC_CONNECTED mode, if DRX operation is configured on a UE, then the UE is allowed to monitor the Physical Downlink Control Channel (PDCCH) discontinuously using the DRX operation. In general, the UE shall monitor the PDCCH during the ON Duration, and may stop monitoring the PDCCH during the Opportunity for DRX Duration. While the DRX cycle length and the On Duration are fixed under a certain DRX configuration, the Active Time (i.e., the duration when the UE is active for possible RX and TX) is extendable from the ON Duration, which may happen during the Opportunity for DRX Duration period. A DRX cycle is controlled via radio resource control (RRC) layer messaging by configuring on DurationTimer, drx-InactivityTimer, drx-RetransmissionTimer, the longDRX-Cycle, the value of the drxStartOffset, and optionally the drxShortCycleTimer and shortDRX-Cycle.

When a DRX cycle is configured, the Active Time in each DRX cycle varies, depending on the configured DRX parameters. The Active Time is extendable from the ON Duration based on the following four conditions. First, the Active Time includes the time while on DurationTimer or drx-InactivityTimer or macContentionResolutionTimer is running. Second, the Active Timer includes the time while a Scheduling Request is sent on PUCCH and the Scheduling Request is pending. Third, the Active Time includes the time while an uplink grant for a pending HARQ retransmission can occur and there is data in the corresponding HARQ buffer. Fourth, the Active Time includes the time while a PDCCH indicating a new transmission addressed to the C-RNTI of the UE has not been received after successful reception of a Random Access Response for the preamble not selected by the UE. If any of the four conditions is met, the Active Time is extended from the ON Duration.

FIG. **7** illustrates examples of LTE DRX traffic patterns with different DRX configuration parameters. In the example of FIG. **7**, all three DRX traffic patterns have a longDRX-Cycle equal to 128 ms. The on Duration parameter, however, is different in different DRX configuration. Under DRX CONFIG#**1**, traffic pattern (**7**A) has an on DurationTimer equal to 100 ms, with DRX-InactivityTimer set to 10 ms. Under DRX CONFIG#**2**, traffic pattern (**7**B) has an on DurationTimer equal to 80 ms, with Drx-InactivityTimer set to 20 ms. Under DRX CONFIG#**3**, traffic pattern (**7**C) has an on DurationTimer equal to 60 ms, with DRX-InactivityTimer set to 40 ms. It can be seen that even under the same DRX duty cycle, the UE may have different ON Duration with different on DurationTimer. Furthermore, the DRX-InactivityTimer can keep the UE stay in Active Time and equivalently extend the ON Duration (i.e., which may happen during the Opportunity for DRX Duration period). Therefore, DRX protocol supports good flexibility on configuration, and different parameter values can lead to various gap patterns in time domain. As a result, DRX protocol may function as a good TDM solution for IDC interference avoidance.

The principle of TDM solution for coexistence system is for eNB to have maximum scheduling flexibility while avoiding coexistence interference by reducing time overlap between LTE and ISM traffic. Therefore, in one example, under TDM solution, the general objective function for coexistence systems is:

$$\text{Maximize } \{\text{Coexistence Efficiency}\} \text{ subject to } \{P_C < P_{C_REQ}\} \quad (1)$$

where

Coexistence Efficiency (CE)=(Duration that eNB can grant resources for LTE TX/RX)/(Observation Time)

Probability to Collide (P_C)=[Duration that eNB can grant resources for LTE TX/RX while ("ISM transceiver can RX/TX" or "GLASS receiver can RX")+extension factor]/(Observation Time)

P_{C_REQ}=the required threshold value of P_C.

Coexistence efficiency (CE) is associated with eNB scheduling flexibility. Higher CE means eNB have more time to possibly schedule data transmission or reception to UE. Probability to collide (P_C) means the level of possibility that coexistence interference may happen. The real collision probability further considers the probability that eNB schedules DL/UL grant and the probability that ISM system schedules UL/DL grant or the probability that GNSS system performs DL reception. Because the LTE sub-frame boundary may not be 100% aligned with ISM or GNSS system, additional probability to collide may be increased due to converting the problem into an integer-programming problem. In addition, the extension factor is introduced in this example to capture the variation of the DRX boundary condition, which is a positive value and thus may further increase the probability to collide.

From LTE perspective, the general objective for coexistence systems is to maximize eNB scheduling flexibility (e.g., a function of CE) while limit coexistence interference probability (e.g., a function of P_C) to be less than a required threshold P_{C_REQ}. P_{C_REQ} may be defined based on the traffic pattern and QoS requirements associated with ISM transceiver or GNSS receiver. In one example, P_{C_REQ} may be 10% for voice traffic based on affordable QoS degradation allowed by user. In another example, P_{C_REQ} may be 0% for critical system information to be exchanged by ISM transceiver (e.g., WiFi beacon or BT initial connection setup).

FIG. **8** illustrates traffic pattern and scheduling parameters of an LTE system and an ISM target system for coexistence problems. Assume that periodic radio signals are transmitted in the ISM target system (e.g., WiFi Beacon), and that DRX operation is enabled in the LTE system. The following traffic scheduling parameters are illustrated in FIG. **8**:

T_{target}: Periodicity of the signal transmitted in target system

$t_{transmit}$ (m): Transmission time over m-th transmission

$T_{onDuration}$: on DurationTimer configured by eNB

$T_{longDRX\text{-}Cycle}$: longDRX-Cycle configured by eNB

$t_{DRX\text{-}Inactivity}$ (n): Extended on Duration time by DRX-Inactivity timer in n-th DRX cycle

T_{offset}: time offset between 1^{st} DRX cycle start point and the incoming signal in target system

Based on the above-illustrated traffic scheduling parameters, both coexistence efficiency (CE) and probability to collide (P_C) can be calculated. As a result, the best suitable DRX configuration parameters can be determined by the eNB to satisfy the general objective of function (1), under the assumption that the eNB knows the exact signal transmission timing and periodicity of the target system.

It is, however, a difficult task to achieve the general objective function (1). First, the eNB typically does not know the traffic scheduling parameters of the target system and thus will not be able to determine the best DRX configuration parameters. Second, the traffic scheduling parameters of the target system may be complicated and unpredictable. To address the first issue, the eNB needs to rely on the UE with in-device coordination capability to recommend preferred DRX configuration. Referring back to FIG. **5**, for example, eNB**51** relies on the coexistence pattern information sent from LTE radio module **54** to determine the preferred DRX configuration parameters. To address the second issue, simplified periodic traffic patterns such as the WiFi beacon signal may be used as a starting point to investigate potential DRX-based solutions for coexistence problems.

FIG. **9** illustrates examples of various LTE DRX configurations that coexist with WiFi Beacon. In the example of FIG. **9**, the WiFi Beacon traffic pattern (**9**A) has a signal periodicity of 102.4 ms, and the WiFi beacon signal transmission duration is less than 3 ms in general. For LTE DRX CONFIG#**1**, traffic pattern (**9**B) has a longDRX-Cycle of 128 ms, and an on Duration=100 ms. For LTE DRX CONFIG#**2**, traffic pattern (**10**C) has a longDRX-Cycle of 128 ms, and an on Duration=80 ms. For LTE DRX CONFIG#**3**, traffic pattern (**10**D) has a longDRX-Cycle of 128 ms, and an on Duration=60 ms. Assume that the first LTE DRX cycle boundary has been aligned with the WiFi beacon. If t_{WiFi_Rx} denotes the time to receive WiFi beacons, and t_{LTE_Tx} denotes the time to have possible LTE UL TX, and x denotes the longDRX-Cycle, then we have:

$$\text{Coexistence Efficiency CE}=\text{Sum}(t_{LTE_Tx})/[102,4,x] \tag{2}$$

$$\text{Probability to Collide } P_C=\text{Probability}(t_{WiFi_Rx}=t_{LTE_Tx}) \tag{3}$$

To satisfy the general objective as defined by function (1), the coexistence efficiency (CE) will be increased if t_{LTE_Tx} is increased. On the other hand, the probability to collide P_C that the WiFi beacon will collide with LTE TX will also be increased if t_{LTE_Tx} is increased. Although changing t_{LTE_Tx} may result in contradictory performance, it is still possible to find the best tradeoff. As illustrated in FIG. **9**, when the on Duration is decreased to 60 ms, there is less collision between the WiFi beacon and possible LTE traffic. Therefore, it is possible to determine which DRX configuration parameters can provide the best solution to avoid IDC interference between LTE and WiFi beacon.

FIG. **10** is a simulation diagram of Probability to Collide vs. Coexistence Efficiency under different DRX configuration parameters. The simulation considers that the LTE eNB can configure DRX parameters for UE to perform coexistence interference avoidance with WiFi beacon for in-device WiFi transceiver. The WiFi beacon periodicity is 102.4 ms, and the WiFi beacon transmission time is 1-3 ms. The DRX parameters to be controlled are the longDRX-Cycle and the on DurationTimer. It is assumed that the drx-InactivityTimer=1 ms, and no grant scheduled by eNB in the last subframe of the on Duration to reduce simulation complexity. At the system level, it is further assumed that the eNB knows WiFi beacon is the subject for coexistence, and the eNB knows the WiFi beacon transmission timing and periodicity.

From the simulation result in FIG. **10**, it can be seen that good tradeoff between "probability to collide" and "coexistence efficiency" may be achieved by proper DRX configuration. More specifically, the DRX patterns with longDRX-Cycle=128 ms or 64 ms can lead to the best performance tradeoff. For example, if longDRX-Cycle=128, when on DurationTimer is small, e.g., when coexistence efficiency is less than 0.17, then the probability to collide is almost zero. Therefore, DRX-based solution is a feasible TDM solution for in-device coexistence interference avoidance.

In one advantageous aspect, the eNB may restrict flexible extension of the ON duration to reduce collision probability. Although DRX protocol supports extendable ON Duration (e.g., the four conditions described above with respect to FIG. **6**), such extendibility may increase collision probability. This is because the in-device WiFi radio may put all traffic over the "Opportunity for DRX Duration" period to avoid the "ON Duration", serious collision may happen if the eNB flexibly extends the ON Duration based on those four conditions. It is thus proposed that at least one of the conditions is disabled (e.g., disable the drx-InactivityTimer) to restrict eNB flexibility and provide in-device radio more reliable protection. It should be noted that those condition(s) would only be disabled when UE indicates it has coexistence interference problem and will not be applied under normal scenario. In one example, a UE transmits an IDC interference indicator to the eNB when IDC interference is detected and IDC interference avoidance mechanism is triggered. Upon receiving the IDC interference indication, the eNB disables some of the conditions to restrict the flexible extension of the ON Duration. In another example, the UE transmits an indicator to the eNB to restrict the flexible extension of the DRX ON Duration once the UE detects IDC interference.

Other possible TDM solutions for IDC interference avoidance may include Semi-Persistent Scheduling (SPS), measurement gap, MBMS subframe, scheduling via PDCCH, and a new protocol. As compared to those solutions, DRX is the most promising solution because it is one of the existing protocols available in Rel-8/9 specification and is applicable for both RRC_Connected mode and RRC_Idel mode. Multiple DRX configuration parameter vales can lead to various gap patterns, to optimize coexistence efficiency and reduce probability to collide. In addition, if some modifications are allowed, the DRX is still the most promising solution because more parameters or additional values of existing parameters may be considered for higher efficiency.

FIG. **11** illustrates possible modifications on existing DRX protocol. Various traffic patterns can be generated by jointly utilizing longDRX-CycleStartOffset, on DurationTimer, drx-InactivityTimer, and shortDRX-Cycle to configure gap pattern for coexistence. In addition, drx-InactivityTimer may help to further improve coexistence efficiency. In the example of FIG. **11**, DRX traffic pattern (**11**A) is based on longDRX-CycleStartOffset and drx-InactivityTimer, DRX traffic pattern (**11**B) is based on shortDRX-Cycle, and DRX traffic pattern (**11**C) is based on based on longDRX-CycleStartOffset, drx-InactivityTimer, and shortDRX-Cycle.

FIG. **12** is a flow chart of a method of TDM solution for IDC interference avoidance from UE perspective in accordance with one novel aspect. A UE comprises a first radio module co-located with a second radio module in the same device platform. In step **1201**, the first radio module obtains traffic or scheduling information of the second radio module. In step **1202**, the first radio module determines a desired TDM pattern based on the traffic and scheduling information to mitigate IDC interference. In step **1203**, the first radio module detects IDC interference based on interference measurement result and triggers interference avoidance mechanism. In step **1204**, the first radio module transmits coexistence pattern information based on the desired TDM patter to a base station when IDC interference avoidance mechanism is triggered. The coexistence pattern information may comprises a recommended TDM pattern periodicity and a scheduling period to maximize IDC efficiency subject to limited level of IDC interference possibility.

FIG. **13** is a flow chart of a method of TDM solution for IDC interference avoidance from eNB perspective in accordance with one novel aspect. In step **1301**, the eNB receives coexistence pattern information from an LTE radio module co-located with a second radio module in a same device platform. In step **1302**, the eNB determines a set of DRX configuration parameters for the LTE radio based on the received coexistence pattern information to mitigate IDC interference. In step **1303**, the eNB restrict flexible extension of the ON Duration within each DRX cycle to further reduce collision probability once the eNB receives an IDC interference indication.

Although the present invention has been described in connection with certain specific embodiments for instructional purposes, the present invention is not limited thereto. For example, although an LTE/LTE-A or WiMAX mobile communication system is exemplified to describe the present invention, the present invention can be similarly applied to other mobile communication systems, such as Time Division Synchronous Access (TD-SCDMA) systems. Accordingly, various modifications, adaptations, and combinations of various features of the described embodiments can be practiced without departing from the scope of the invention as set forth in the claims.

What is claimed is:

1. A method comprising:

obtaining, by a first radio module, traffic or scheduling information of a second radio module co-located with the first radio module in a wireless communication device;

determining a desired time-division multiplexing (TDM) pattern for the first radio module based on the traffic or scheduling information to mitigate in-device coexistence (IDC) interference with the second radio module; and

transmitting coexistence pattern information based on the desired TDM pattern to a base station, wherein the coexistence pattern information comprises a set of recommended discontinuous reception (DRX) configuration parameters defined in long-term evolution (LTE) 3GPP standards and a time offset between a first DRX cycle start point and an incoming signal of the second radio module.

2. The method of claim **1**, wherein the coexistence pattern information comprises a recommended TDM pattern periodicity and a scheduling period.

3. The method of claim **1**, wherein the set of DRX configuration parameters comprises an onDurationTimer, a DRX cycle, a DRX-Inactivity timer for on Duration extension.

4. The method of **3**, wherein a long DRX-Cycle is 128 ms or 64 ms, and wherein the second radio module is a WiFi radio module having WiFi beacon signal periodicity of 102.4 ms or multiple of 102.4 ms.

5. The method of claim **3**, wherein the onDurationTimer is small enough such that collision probability between the first and the second radio modules is lower than a threshold value.

6. The method of claim **3**, further comprising:

transmitting an IDC interference indicator to the base station such that flexible extension for an ON duration in each DRX cycle is restricted to reduce collision probability between the first and the second radio modules.

7. The method of claim **1**, further comprising:

triggering an IDC interference mitigation mechanism based on an IDC interference measurement result, wherein the coexistence pattern information is transmitted to the base station when the IDC interference mitigation mechanism is triggered.

8. A wireless communication device, comprising:

a first radio module that obtains traffic or scheduling information of a second radio module co-located with the first radio module;

a control entity that determines a desired time-division multiplexing (TDM) pattern for the first radio module based on the traffic or scheduling information to mitigate in-device coexistence (IDC) interference with the second radio module; and

a transmitter that transmits coexistence pattern information based on the desired TDM pattern to a base station, wherein the coexistence pattern information comprises a set of recommended discontinuous reception (DRX) configuration parameters defined in long-term evolution (LTE) 3GPP standards and a time offset between a first DRX cycle start point and an incoming signal of the second radio module.

9. The device of claim **8**, wherein the coexistence pattern information comprises a recommended TDM pattern periodicity and a scheduling period.

10. The device of claim **8**, wherein the set of DRX configuration parameters comprises an onDurationTimer, a DRX cycle, a DRX-Inactivity timer for on Duration extension.

11. The device of claim **10**, wherein a long DRX-Cycle is 128 ms or 64 ms, and wherein the second radio module is a WiFi radio module having WiFi beacon signal periodicity of 102.4 ms or multiple of 102.4 ms.

12. The device of claim **10**, wherein the onDurationTimer is small enough such that collision probability between the first and the second radio modules is lower than a threshold value.

13. The device of claim **10**, wherein the device transmits an IDC interference indicator to the base station such that flexible extension for an ON duration in each DRX cycle is restricted to reduce collision probability between the first and the second radio modules.

14. The device of claim **8**, wherein the device triggers an IDC interference mitigation mechanism based on an IDC interference measurement result, wherein the coexistence pattern information is transmitted to the base station when the IDC interference mitigation mechanism is triggered.

15. A method comprising:

receiving time-division multiplexing (TDM) coexistence pattern information from a first LTE radio module in an long-term evolution (LTE) 3GPP wireless system, wherein the first LTE radio module and a second radio module are co-located in a same device platform, and wherein the coexistence pattern information comprises a set of recommended discontinuous reception (DRX)

configuration parameters defined in long-term evolution (LTE) 3GPP standards and a time offset between a first DRX cycle start point and an incoming signal of the second radio module; and

determining a set of discontinuous reception (DRX) configuration parameters for the first radio module based on the TDM coexistence pattern information to mitigate in-device coexistence (IDC) interference between the first LTE radio module and the second radio module.

16. The method of claim **15**, wherein the coexistence pattern information comprises a recommended TDM pattern periodicity and a scheduling period.

17. The method of claim **15**, wherein the set of DRX configuration parameters comprises an onDurationTimer, a DRX cycle, a DRX-Inactivity timer for onDuration extension.

18. The method of **17**, wherein a longDRX-Cycle is configured to be 128 ms or 64 ms, and wherein the second radio module is a WiFi radio module having WiFi beacon signal periodicity of 102.4 ms or multiple of 102.4 ms.

19. The method of claim **17**, wherein the onDurationTimer is configured to be small enough such that collision probability between the first and the second radio modules is lower than a threshold value.

20. The method of claim **17**, further comprising:

receiving an IDC interference indication; and

restricting flexible extension of an ON duration within each DRX cycle to reduce collision probability between the first and the second radio modules.

* * * * *